

**Summary of a Symposium on Cloud Systems, Hurricanes and TRMM:
Celebration of Dr. Joanne Simpson's Career - The First 50 years**

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Abstract

A symposium celebrating the first 50 years of Dr. Joanne Simpson's career took place at the NASA/Goddard Space Flight Center from December 1 - 3, 1999. This symposium consisted of presentations that focused on: historical and personal points of view concerning Dr. Simpson's research career, her interactions with the American Meteorological Society, and her leadership in TRMM; scientific interactions with Dr. Simpson that influenced personal research; research related to observations and modeling of clouds, cloud systems and hurricanes; and research related to the Tropical Rainfall Measuring Mission (TRMM). There were a total of 36 presentations and 103 participants from the US, Japan and Australia. The specific presentations during the symposium are summarized in this paper.

1. Introduction

A symposium celebrating the first 50 years of Dr. Joanne Simpson's career took place at the NASA/Goddard Space Flight Center from December 1 - 3, 1999 and was sponsored by NASA Headquarters and the NASA Goddard Space Flight Center Laboratory for Atmospheres. Dr. Simpson received her Ph. D. from the University of Chicago in 1949 and was the first US female to obtain a Ph. D. in Meteorology. She served as the American Meteorological Society President in 1989, and Project Scientist for the Tropical Rainfall Measuring Mission (TRMM) from 1986 to its successful launch in December 1997. She joined NASA Goddard in 1979 and currently serves in the position of Chief Scientist for Meteorology, Earth Science Directorate, NASA Goddard Space Flight Center.

Dr. Simpson's major areas of scientific research involved the "*hot tower*" hypothesis and its role in hurricanes, structure and maintenance of trade winds, air-sea interaction, and observations and the mechanism for hurricanes and water spouts. She was also a pioneer in cloud modeling with the first one-dimensional model and had the first cumulus model on a computer. She led the work into multi-dimensional cloud modeling via observations of mergers and cloud interactions in lines. She played a major role in planning and leading observational experiments on convective cloud systems, such as the joint NOAA-Navy Project Stormfury, and the Florida Area Cumulus Experiment. She was a leading participant in the aircraft aspects of several GARP experiments, particularly GATE, MONEX and TOGA/COARE.

This symposium consisted of presentations that focused on: (1) historical and personal points of view concerning Dr. Simpson's research career, her interactions with the American Meteorological Society, and her leadership in TRMM; (2) scientific interactions with Dr. Simpson that influenced personal research; (3) research related to observations and modeling of clouds, cloud systems and hurricanes; and (4) research related to the TRMM. The specific presentations are summarized below from reports submitted by the Goddard session chairs.

2. Session summaries

2.1. Opening session

This session was chaired by Dr. F. Einaudi (Goddard Space Flight Center) and Professor M. Geller (University of New York).

The Center Director Al Diaz opened the symposium with a welcome. Mr. Diaz acknowledged Joanne's many accomplishments, including her role as TRMM Project Scientist, her authorship of over 190 refereed publications and her leadership in the area bridging science and technology. He cited her as a role model for people in science and for her dedication to service to the science community, both nationally and internationally. He proclaimed that a three-day symposium is well worth the celebration of the career of Dr. Simpson.

Dr. Ramesh Kakar, NASA/HQ TRMM Program Scientist and Mesoscale Program Manager hailed Joanne as one of the best mesoscale meteorologists of the century! Dr. Kakar told an amusing anecdote about Joanne's use of the "Washington Monument Defense" (the thinly-veiled threat to close the famous monument in the face of budget cuts) as a successful method of combating proposed NASA budget cuts in the mesoscale program. He facetiously urged Joanne to "get busy" analyzing data from the numerous TRMM field campaigns for the past several years.

Vince Salomonson, the Director of Earth Sciences at Goddard Space Flight Center spoke next. He talked briefly of the upcoming launches that will impact the Earth Sciences (Terra, EOS/AM, etc). He cited as his first "connection" to Joanne his association with Hebert Riehl at Colorado State University in the 1960's. He noted Joanne's important role in securing TRMM funding early in the program. He remarked that conducting Joanne's annual Performance Appraisal is always interesting, as she consistently outperforms most other employees. Dr. Salomonson noted with pride that the most powerful computer at Goddard is named in honor of Dr. Simpson.

Dr. Ghassem Asrar, The Associate Administrator for Earth Science, NASA/HQ, gave the keynote speech of the symposium. Dr. Asrar began by talking about the Earth Science Enterprise, how it must examine all aspects of the earth-atmosphere-ocean system and their interactions, coupled with a strong modeling component. He noted that Joanne, in her role as TRMM Project

talking about the Earth Science Enterprise, how it must examine all aspects of the earth-atmosphere-ocean system and their interactions, coupled with a strong modeling component. He noted that Joanne, in her role as TRMM Project Scientist, laid the foundation for this. He went on to say that Joanne was a vociferous advocate for new measurements, rounded up the support of the community-at-large and kept the program in focus. He noted that TRMM set new frontiers in partnership- "a new era of collaboration"- and cited John Theon for his continued presence in TRMM even into retirement! He cited the absence of Chris Kummerow as an example of the spirit of this cooperation with Japan. He pointed out that Joanne's role in TRMM as just one example of her approach to life and science: do everything fully, keep the big picture in mind, and let the "smart" people, as she called them, handle the intermediate steps. He noted that although Joanne was the first woman to obtain a Ph.D. in Meteorology in this country, she never used that distinction for herself, and always saw to it that women got their fair shot in science. He concluded by noting that Joanne had spent a lifetime refining her thinking in cloud modeling.

2.2 Goddard and Beyond

This session was chaired by Dr. R. Adler (Goddard Space Flight Center), Dr. L. Uccellini (NOAA's National Centers of Environmental Prediction (NCEP)), Dr. G. Heymsfield (Goddard Space Flight Center) and Dr. G. North (Texas A&M University).

Dr. Franco Einaudi, Chief of Goddard's Laboratory for Atmospheres, gave an overview of Joanne Simpson's career, as a scientist, as a manager, and as a role model for women. The influence of Joanne's parents on her desire to lead her own professional life and the influence of her father's interest in aviation were described. That early interest in aviation led Joanne to an interest in weather and to a meeting with Professor Rossby at the University of Chicago, which led to her beginning in meteorology. Joanne had stated "Within ten minutes I was entrained into his orbit." Later her meteorology training led to her teaching meteorology courses for aviation officers at both Chicago and NYU during the war. She was one of seven women out of 200 students in that meteorology training course, and Joanne likes to note that all seven were near the top of the class. Joanne became Herbert Riehl's student at the University of

Chicago focusing on the study of convective clouds. Rossby commented initially that that was a good topic "for a girl", because it was not important. After receiving her Ph.D. Joanne started her experimental career at Wood's Hole, moving on to NOAA, the University of Virginia and in 1979 to Goddard as head of the Severe Storms Branch and later as the project Scientist of TRMM.

Her many awards include the AMS Rossby Medal, the Department of Commerce's Gold and Silver Medals and NASA's Exceptional Scientific Achievement Medal. She has devoted herself to the AMS and served in many positions culminating in the Presidency of the organization. The influence and support of her science partner and husband Bob Simpson was described.

Professor Eugenia Kalnay of the University of Maryland discussed "*Joanne Simpson as a Role Model*", initially contrasting the role of women in science in her native Argentina, where their involvement was considerable, to that in the U.S. when she arrived at graduate school. Joanne's model as a leader in opening opportunities for women in science leadership positions was noted and provided an example for Professor Kalnay to follow when she became a branch head in the same Goddard laboratory as Joanne. At the end of this talk Joanne stated that she had been "the role model for women in meteorology" for long enough and resigned that position and passed the mantle on to one or more of the women scientists in the audience.

"*The Experimental Meteorology Laboratory (EML) and University of Virginia Years With Joanne Simpson-An Ideal Model of Mentorship*" was the title of the talk given by Professor Roger Pielke, Sr. of Colorado State University. At EML Joanne provided not only the scientific leadership but the managerial leadership in providing the environment and resources for young scientists to accomplish their research. Roger moved with Joanne to the University of Virginia and observed her positive interactions with students and was also involved with Joanne and Bob Simpson in private sector work with Simpson Weather Associates. The Florida Area Cumulus Experiment (FACE) and Joanne's role as experiment leader was discussed. Early work on cumulus mergers were described along with recent work that continues to build on that early research, including the modeling of the impact of land use change over the decades in South Florida. This most recent work is a direct descendant of the

shifting of centers of convection and thunderstorms from one location to another due only to the land use change on a global basis.

Dr. Louis Uccellini, Director of NOAA's National Centers of Environmental Prediction (NCEP) described Joanne's role as head of NASA Goddard's Severe Storm Branch from 1979-1988. Louis described Joanne's role in developing the branch's strategic plan to carry out research in storm processes related to deep convection and both tropical and extratropical cyclones. The role and personnel of the branch's two groups were described via words and pictures and the branch's growth to involve modeling at various scales and precipitation estimation from space using microwave and infrared techniques was described. These early efforts evolved into involvement in the TRMM project and related activities. Key scientific advances related to jet streaks and winter storm intensification and modeling and observation of deep convection were described. Joanne's leadership provided the basis for a careful blending of observations and modeling to successfully investigate storm processes at both cloud and regional scales. In addition, Joanne provided an excellent environment for leadership training for many members of the branch.

Mr. Bob Ryan of NBC Channel 4 in Washington, and Dr. Richard Hallgren from the American Meteorological Society (AMS) led a tag team presentation on Joanne's association with the AMS and her many strong connections with it. Joanne has had an enormous involvement with the AMS which she joined in 1941. The two speakers talked about the many AMS committees which Joanne has served, as well as the many honors she has received. Joanne has served as Councilor of the Society for two terms, was a member of the Executive Committee for three terms, and served as President of the AMS. These activities all show Joanne's strong commitment to the AMS. She has served on the Committee on Women and Minorities and has been influential in involving women in Meteorology. And she has been a member of the Committee on Tropical Meteorology and Hurricanes for many years. The speakers then went over some of Joanne's scientific accomplishments, which are many. She has performed outstanding experimental work in cumulus investigations for which she later received the most prestigious AMS Rossby Award (1983). She has published over 175 papers in AMS and other journals, and has been a consulting

editor for various journals. Finally, the speakers praised the high level of excitement that Joanne has brought to the AMS over the years. At the completion of the presentation, Joanne stood up and thanked the speakers. She stated her strong commitment for the AMS in bringing together the operational, research, and broadcasting communities.

Dr. Mike Manton of the Bureau of Meteorology in Melbourne (BMRC) Australia presented "*Joanne and BMRC*". Joanne has been known to bring people from the international community together. One of these strong connections has been with scientists from Australia. Mike recollected on this breadth and depth of Joanne's influence on the Australian meteorological community. These connections began in the 1960's with people such as Tom Fink, former Chief Scientist of the Department of Defense, Bruce Morton, former head of the Department of Mathematics at Monash University, and Jack Warner of CSIRO. Fink was the engineer who provided advice on the instrumenting a glider for making measurements of thermals in the atmosphere. Morton collaborated with Joanne on water spout modeling and observation studies. And Jack Warner was involved similar to Joanne with observations and modeling of cumulus convection. These excellent interactions as well as those with younger scientists, later led to a series of field experiments near Darwin (AMEX-EMEX-STEP). This experiment initiated the pre-TRMM ground validation program with the deployment of the TOGA radar which stayed in Darwin from 1987 to 1991. Darwin provided a good ground validation for TRMM to look at the role of violent thunderstorms associated with islands in the tropics. The Darwin site also provided excellent climatological data for TRMM. Several experiments followed in Australia (ITEX, DUNDEE, MCTEX) or involving Australians (SCSMEX). Joanne maintained strong connections with these experiments and was highly supportive of them. Joanne and Bob Simpson were both involved with ITEX aircraft observations with interest in the similarities between Florida and Darwin cumulus and the role of mergers in both regions. At the conclusion, Dr. Manton recollected on Joanne's liveliness in the international community and her profound influence on science. He stated the great appreciation that BMRC has for science interactions with Joanne, and for the development of the TRMM ground validation effort.

Dave Atlas completed the session with a talk reminiscing about the many years of his association with Joanne, and some of the early developments in Radar Meteorology related to her work. He spoke of Joanne's "phenomenal enthusiasm for all of Meteorology" and speaks of her as a "mythical figure". Joanne was the first woman to receive the AMS Meisenger Award for her excellent work on air-sea interaction and heat island effects. The presentation then progressed onto some of the early history of hurricane work in the 1940's performed with radars. He also talked about the early work on thunderstorm research by Byers, Braham, Battan, and others in which radar techniques were just being developed to probe the internal reflectivity structure. Atlas then progressed onto spaceborne radar detection of outflow boundaries produced by thunderstorms. These observations were reminiscent of Joanne's earlier work on convective development along mergers of sea breeze fronts. The presentation, then, progressed onto the National Hail Research Experiment (NHRE) in which hail suppression research was the focus. Joanne provided advice to this experiment because of her prior efforts in Florida with cloud seeding. Finally, Atlas commented on Joanne's exciting research in her last two decades at the Goddard Space Flight Center. He concluded with his admiration for Joanne and her "inspiring enthusiasm, bottomless well of good ideas, her ability to attract bright young people who then paid their loyalty to her, and she has one final quality that she can stand up to program managers at NASA Headquarters better than anyone else".

2.3 TRMM

This session was divided into two subsessions, TRMM History and TRMM rainfall algorithms, and was chaired by Dr. J. Theon, Dr. E. Smith (Marshall Space Flight Center) Dr. B. Ferrier (University of Maryland at Baltimore) and Dr. C. Kummerow (Goddard Space Flight Center).

In the TRMM History subsession, nearly all of the presentations described Dr. Simpson's critical role in planning the Tropical Rainfall Measuring Mission (TRMM). Theon, Geller, and Fugono primarily discussed Joanne's role within the science community, while LaVigna and Keating primarily the characteristics of the mission and Joanne's interactions with project management. The presentation by Woodley focused on exciting opportunities in advancing our understanding of clouds and precipitation using TRMM data. Each presenter

remarked on Joanne's enthusiasm, energy, and appreciation of everyone's efforts in advancing the cause of TRMM.

Dr. John S. Theon, the original NASA Program Scientist for TRMM, described his working relationship with Joanne in promoting the mission within NASA and throughout the atmospheric science community. Theon described his early research interests in the role of diabatic heating on the dynamics of weather systems. He also gave the background to the early concept of TRMM. In 1984 TRMM was selected for further study as one of a dozen proposals for new missions promoting meteorological research within NASA. The support for TRMM grew in the scientific community under the leadership of Dr. Gerald North, who was the Project Scientist until he left Goddard Space Flight Center (GSFC) for Texas A&M University in 1986. Shortly thereafter Joanne was recruited to serve as Project Scientist for the mission. She urged many prominent people in the atmospheric science community to write letters to their congressional representatives supporting TRMM. Of particular importance was Vern Suomi's enthusiastic support for the mission. As President of the American Meteorological Society (AMS), Joanne met with the Congressional Subcommittee on Science and Technology. She had learned that the minority leader of the subcommittee (Rep. Bill Green, R-NY) was interested in weather and convinced him to support the mission. Representative Green subsequently attached a rider to the FY91 NASA appropriation bill providing an additional \$50M and directing NASA to use it for a new start for TRMM. Joanne's leadership of the science team was also key in persuading the National Academy of Sciences advisory panels to support TRMM, as well as convincing NASA senior management of the mission's feasibility.

Mr. Thomas A. LaVigna, former TRMM Project Manager, spoke of working with Joanne while managing the project. Mr. LaVigna was the Deputy Project Manager for the Gamma Ray Observer prior to working on TRMM in 1991. Before the end of the year, he became Acting Project Manager at the same time that TRMM received its first major funding for hardware development. He was officially named Project Manager early in 1992, and thereafter managed the mission at GSFC for an additional 6 years until several months after the satellite's launch. He noted that Joanne worked closely with him and his team in overcoming many challenges facing the mission, some of them associated

with the international partnership with Japan. TRMM was the largest observatory ever designed, developed, and tested within GSFC, in which as many as 400 people worked on the project during peak activity. The TRMM Science Data Information System (TSDIS) and Mission Operations were also designed at GSFC. Among the difficulties faced by the project were a tight budget, establishing a cooperative science program between two separately organized science teams in the US and Japan, various technological challenges, developing a science processing system that could handle large volumes of data, and changes in the launch schedule. LaVigna showed pictures of the satellite and mission schedules. He noted that Joanne worked closely with other key scientists in convincing Japan not to delay the satellite launch until February 1998, thereby allowing for more complete observations of the anticipated El Niño starting in late 1997. TRMM remained on schedule and within budget, which is rarely achieved within any space agency. The satellite continues to experience excellent performance, and it is expected that the mission will last nearly twice as long as originally planned.

Professor Marvin Geller from the State University of New York at Stonybrook described the people and events that shaped the formative stages of TRMM. He traced the beginning of TRMM back to the 1970's when rainfall was first estimated from the ESMR (Electronically Scanning Microwave Radiometer) observations on Nimbus-5 and from visible/infrared observations from geostationary satellites. The next major step was when Dr. David Atlas invited Dr. Nobuyoshi Fugono to a workshop at GSFC on measuring precipitation from space in 1981. Dr. Fugono was recognized for his important work in the remote measurement of rainfall from aircraft using combined active (radar) and passive microwave radiometry as well as his active endorsement and promotion of TRMM in Japan (also noted by Theon in his presentation). Geller then credited Theon for originating and promoting the concept of small meteorological research satellites within NASA through a call for proposed missions in 1984. The concept of TRMM was one of the proposals from Goddard, which was to enable the statistical determination of rainfall at low latitudes (North) using visible/infrared techniques, passive microwave radiometry (Wilheit), and radar measurements from a low altitude, highly inclined satellite. Extensive surface observations would validate the spaceborne rain retrievals (Thiele). After North left GSFC in 1986, Geller and Theon asked Joanne to first be the Study Scientist,

and later the Project Scientist, for TRMM. He noted that Joanne's tenure as Project Scientist lasted 11 years, longer than any other position during her distinguished, 50-year career. She became good friends with hardware engineers, software engineers, and project managers in the US and in Japan. Geller identified several key people who helped make TRMM successful. Joanne's scientific and administrative leadership, along with her great stature in both countries, elevated the scientific discussion and added momentum to a process that resulted in a successful mission.

Dr. Nobuyoshi Fugono, Communications (formerly Radio) Research Laboratory in Japan, discussed the planning of TRMM from the Japanese perspective. Fugono has worked in space sciences for more than 40 years, being involved in more than 100 projects working with sounding rockets and satellites. He began studying the measurement of rain from space back in 1976, and within four years performed the first flight experiments of a dual frequency airborne scatterometer/radiometer. Fugono remarked on the collaboration with Atlas through his participation in a GSFC workshop on measuring precipitation from space in 1981, discussions of possible collaboration in an airborne experiment in 1983, and the proposed TRMM from GSFC in 1984. Joint activities between GSFC and RRL accelerated in 1985 with the first joint airborne rain measuring experiment, making TRMM a joint mission between the US and Japan, and a TRMM workshop. Negotiations between high-level officials in NASA and in Japan in 1986 were followed by numerous planning meetings and workshops in 1987. The final report of the feasibility study was signed between the US (NASA) and Japan (Space and Technology Agency) in 1988. Fugono remarked that international programs are difficult because of differences in fiscal year cycles, contrasting responsibilities and functions of agencies in different countries. Joanne's leadership was especially important during these challenging and difficult times. For example, Joanne's involvement in the planning of TRMM was a contributing factor in fostering the interest of Prof. Taroh Matsuno, who was very influential in Earth Science advisory committees in Japan.

Dr. William Woodley then gave a scientific presentation of his ongoing work with Professor Daniel Rosenfeld (Hebrew University) in studying the impact of cloud-aerosol interactions on precipitation using TRMM data. Woodley also gave humorous accounts of his relationship with Joanne since his

days as an undergraduate at UCLA in the early 1960's. The interpretation of the TRMM data, principally from the Visible Infrared Scanner (VIRS), is based on the concept that variations in the number concentrations of cloud condensation nuclei (CCN) affect the microphysical properties of clouds. Coalescence production of rain may be substantially delayed in clouds that ingest high number concentrations of CCN, such as in areas with polluted air, resulting in greater amounts of supercooled cloud water and enhanced growth of precipitation at temperatures below 0 °C. Woodley showed evidence of reduced radar-derived rainfall volumes in conditions where coalescence growth of rainfall was greatly diminished. Several examples of the impact of smoke and pollution upon the effective radius of cloud particles in convective clouds as a function of temperature were shown using multispectral analyses of satellite images. The microphysical classification is applied to different zones as a function of height. Limited aircraft validation revealed large mass contents (up to 3 g m^{-3}) of supercooled cloud water observed at temperatures colder than -30 °C in growing convective towers over Thailand and West Texas. TRMM Precipitation Radar (PR) data also showed the absence of echoes in areas where clouds formed in polluted air. Woodley speculated that atmospheric pollution may have an impact on our climate through inadvertent modifications in the atmospheric hydrologic cycle.

Mr. Thomas Keating, former TRMM Systems Engineer, recounted key personnel and major decisions made during the early years of TRMM. He described the initial satellite configuration at the start of the Phase A study in 1985. He also described the US-Japan feasibility study, listing many of the events described in Fugono's talk. Mission costs were reduced in 1988 in response to budgetary concerns by selecting a slightly higher altitude, a revised propulsion system, and a different launch vehicle. But the biggest change was the elimination of the 35 GHz frequency, which also effectively reduced the total mass of the satellite and the required rates of data transmission. Simpson and Atlas saved the mission by arguing that the objectives could still be met using a single frequency. Joanne's role in soliciting support from the scientific community was particularly important during this time. Keating then recalled the visit of key staff members from Rep. Green in 1988, which led to the congressional appropriation that directed NASA to fund a new start for TRMM in 1991 (also discussed by Theon). Shortly thereafter the final instrument

complement was defined. Keating then gave an interesting account of important actions made by key individuals that ultimately led to TRMM's success. He then warned that the meteorological community needs to be particularly careful and vigilant in its selection of frequencies in future missions, since it is now possible for the commercial satellite industry to operate in the microwave frequencies used by weather radars.

Gerald North (Texas A&M) began his talk by giving a detailed history of the TRMM project from the science team perspective. Gerry believes that TRMM got its start from a 1981 conference on precipitation at Goddard organized by Dave Atlas and Otto Thiele. The first memos were circulated during the summer and fall of 1984, referring to a tropical energy budget experiment. By 1985, Japan (via Fugono) was interested and in November 1985 a Science Steering Group Workshop was held. North presented four challenges there: sampling, the diurnal cycle, beam filling and ground truth. With the framework set up, papers began to be published on the issue of sampling, beginning with a paper by McConnell in 1987. Other followed, notably papers first authored by Tom Bell, Ben Kedem, Kyung-Sup Shin and Long Chiu. GATE rain statistics played a prominent role in most of these papers.

Tom Wilheit (Texas A&M) opened his talk by reminiscing about how he first met Joanne during GATE in 1974. He went on to talk about the TRMM measurement concept and posed the question, "*Why TRMM?*" He specifically mentioned four topics important in the remote sensing of rainfall: sampling, the diurnal cycle, spatial resolution and modeling assumptions. He discussed the differences and complementary features of radar/radiometer combinations and noted the importance of the sampling error. He postulated about future missions, specifically the GPM or Global Precipitation Mission, which will employ a constellation of radiometers to address the sampling issue. These relatively low-cost radiometers would be in sun-synchronous orbits and tied together by an orbiting radar.

Riko Oki (NASDA, Japan) also opened her talk with an amusing anecdote about her first meeting with Joanne: in the woman's bathroom! She then briefly discussed the issue of the PR calibration and ground validation before summarizing at length the results of other scientists working at NASDA. This

included work on storm height distributions by Dave Short, which indicated the contrasting observations in storm-height between the oceans and the land. His analysis showed a bimodal distribution over oceans, the results of both trade-wind cumulus and deep convection. A correlation was found between TRMM derived storm height and rainfall rate, and estimates of shallow rainfall as a percent of the total were presented. Dr. Oki finished with a description of her work (with Seto and Musiak) on land surface observations with the TRMM PR. This analysis revealed that the annual mean of the surface cross section corresponded to land surface classifications (i.e. vegetation) and that monthly anomalies corresponded to surface soil wetness.

Eric Smith (GHCC/NASA/MSFC) presented an interesting talk in which he not only examined several areas of TRMM research, but also placed them within the context of Joanne's long career. In the area of rain measurements and validation he noted that Joanne's career has been dedicated to the understanding and modeling of the physics and dynamics of clouds and precipitation, and cited her 1975 work on the FACE program as an example. He presented evidence of the diversity in the estimates produced by physical algorithms and combined algorithm methodologies. He noted that Joanne has always inspired new and better ways to validate the estimates. Smith proceeded to talk about the diurnal variability of rainfall, citing papers by Joanne (with Stern and Brier) in the early 1950's) as seminal work. He presented TRMM results on diurnal variability, grouped by algorithm, by season and by land-vs.-ocean. Smith talked about the importance of the retrieval of latent heating, citing the early work by Riehl and Malkus in the late 1950's, contrasting that work to recent results from two different models that utilize TRMM retrievals. Smith finished with a discussion of the synergism between cloud modeling and precipitation remote sensing, noting that Joanne had virtually invented this subject, citing numerous papers between 1953 (on the bubble theory) and 1971 (one-dimensional; cloud models). He noted correctly that cloud models provide the microphysical underpinnings for two of the three TRMM rain algorithms.. He also noted that future work with radiometer-radar measurements would enable refinements to these cloud models, hence the synergy.

Robert Adler (GSFC) gave a talk on the comparison of TRMM results to Pre-TRMM estimates. He began by noting his long association with Joanne,

particularly during the 1980's when she was his Branch Head. He noted that it was in this period that Joanne laid the future foundation for TRMM by creating and sticking to a science plan. Adler notes an amusing way Joanne had of rewarding her employees: personal notes embossed with cartoon stickers of various animals! He suggested some correlation between the frequency of these and subsequent promotions. The scientific part of his talk began by showing (like E. Smith) the diversity and range of estimates from a 1996 workshop. This was reduced somewhat by limiting the analysis to quasi-standard products. He then showed the mean 20 year (1979-1998) global precipitation derived by the Global Precipitation Climatology project (GPCP), a pre-TRMM standard. He presented a composite of EL Niño minus La Niña years, and presented recent results of a one-degree, daily precipitation product derived from SSM/I data. He noted the attention TRMM data has received during the recent hurricane seasons, despite not being designed as an "operational" system. He showed that preliminary results from TRMM are reducing the variability in the latitudinal profile of rainfall compared to the pre-TRMM era. Comparing TRMM results to those from the GPCP revealed that TRMM is about 10% higher. Specifically it is higher in the heavy rain areas and lower in the light rain areas. He noted that in the future, TRMM results might enable us to improve the estimates from the SSM/I and thus extend the period of record back to 1987.

Eric Smith ended the session with a brief tribute to the absent Chris Kummerow, calling him the "unsung hero" of TRMM, particularly for his work in developing the TRMM data system (TSDIS). He also graciously acknowledged the influence of Jim Weinman on Chris' career.

2.4 Hurricanes - Observation and modeling

This session was chaired by Drs. Scott Braun (Goddard Space Flight Center) and Greg Holland (Bureau of Meteorology Research Centre, Australia).

Professor William Gray of Colorado State University started the session with a talk entitled "*Clouds, hurricanes, and climate prediction and why things are going to hell*". He first described the fundamental role that clouds play in climate, particularly because of the importance of vertical energy fluxes relative to horizontal fluxes. He suggested that midlatitude baroclinic waves were much more fundamental to vertical fluxes than poleward fluxes and he criticized

dishpan experiments of the past because they suggested that baroclinic instability governed midlatitude circulations and that latent heating effects were unimportant. Next, Professor Gray discussed what he termed the "coming scourge of hurricane destruction in the U.S." He noted that the later half of the 1990's saw a sharp increase in the frequency of strong hurricanes in the Atlantic, and suggested a return to the stormy years of the 1950-60's. He attributed the increase to multi-decadal cycles driven by sea-surface temperature changes in the Atlantic Ocean. He affirmed the skill of recent seasonal hurricane forecasts and suggested that significant climate signals can provide good statistical skill up to 12 months into the future. Finally, Professor Gray challenged climate modelers to match the skill of empirical climate forecasts and to systematically verify their climate forecasts. He suggested that climate models will never prove to be superior to empirical forecasts because 1) empirical forecasts are based upon prior, consistent trends in past data, and 2) numerical models solve an initial value problem based upon insufficient representations of very complex atmospheric processes with little information from previous observations.

Dr. Richard Anthes from the National Center for Atmospheric Research discussed *"Hot towers and hurricanes-early observations, theories and models"*. He presented numerous examples of what he considered to be "hot towers", equating the term with deep cumulonimbus clouds. He described Dr. Simpson's role in originating the concept of hot towers, their role in hurricane formation and maintenance, and the potential for parameterization of their effects in numerical models. Dr. Anthes reviewed some of the early forms of cumulus parameterization, including linear theory models such as conditional instability of the first and second kinds (CIFK and CISK). Linear theory assumes small random perturbations in a stagnant base state and leads to small-scale disturbances growing most rapidly so that they eventually overwhelm larger-scale circulations. He stated that linear theory has little application to hurricane genesis since the perturbations are not small or random, the base state is not stagnant, and development is nonlinear with evolving static stability. The concept of CISK, while unsuitable for describing the genesis of hurricanes, was beneficial in that it introduced the idea of cooperation between processes on the cumulus scale and hurricane scale. Cumulus parameterizations in the 1960's generally consisted of 1) moist convective adjustment schemes or 2) schemes that related heating and moistening to larger scales as functions of a sounding

and dynamics, .e.g, moisture convergence. An example is the Kuo cumulus parameterization, which appears to be based upon the hot tower concept. While the scheme is not a good physical explanation of actual convective processes, it works well because it adjusts the atmosphere towards a moist adiabatic structure, has a reasonable vertical distribution of heating, and conserves energy. Finally, Dr. Anthes addressed the question of whether hot towers are relevant to hurricanes. In reality, there are many other features and processes that are important in determining the actual evolution of hurricanes, including pre-existing large-scale disturbances, environmental wind shear and static stability, sea-surface temperatures and surface fluxes, stratiform precipitation processes, ice microphysical processes, and radiation. However, he asserts that hot towers are critical to the evolution of hurricanes since without them hurricanes would not exist.

Dr. Greg Holland from the Bureau of Meteorology Research Centre in Australia presented a talk entitled "*Some musing on the history of understanding tropical cyclone development*". He first addressed the issue of what enables the formation of the warm core. Early studies by Dr. Simpson suggested that the warming aloft came from heating within clouds, while others had suggested that the warming arose from subsidence within the eye. Using high-resolution numerical simulations, Dr. Holland suggested that both processes play a role in the formation of the warm core. He reviewed the fact that the available energy in the tropical atmosphere is insufficient to produce the substantial lowering of surface pressure in hurricanes, but that the synergistic effects of lowering surface pressure and increasing surface fluxes of sensible and latent heat can lead to intense pressure falls. The relationship between the hurricane central pressure and the effects of surface fluxes can be quantified in the form of a maximum potential intensity (MPI). In the tropical western Pacific Ocean, the MPI suggests hurricanes with surface pressures as low as 860 mb, but few hurricanes actually attain their MPI. Fifty percent do not get within 60 mb of their MPI. Dr. Holland suggested that cool downdraft air spirals in towards the center and disrupts the upward flow of warm, moist air in the eye wall, thus inhibiting intensification. Dr. Holland also discussed the role of vortex dynamics including vortex merger, which can result in a larger and more intense vortex, and vortex breakdown. He described the existence of vortex Rossby waves on the

cyclonic vortex and discussed possible forcing mechanisms including barotropic instability and convective forcing.

Dr. Kristina Katsaros spoke next on "*Joanne-#1 woman of air-sea interaction*" in which she lauded Dr. Simpson's work on "The air and sea in interaction" (Malkus, 1960). Dr. Katsaros emphasized the importance of surface exchange coefficients and the effects of wind speed and stability, but stated concerns about our lack of understanding about these coefficients in the hurricane boundary layer and the effects of sea state. She presented results from the Surface Wave Dynamics Experiment showing variations of the drag coefficients with swell state and emphasized that larger drag occurs when the waves are going against the wind. While the surface roughness length and drag coefficient increase with wind speed, the roughness lengths for sensible and latent heat decrease with wind speed and the exchange coefficients have little variation with speed. Dr. Katsaros stressed the need for three-dimensional data over large regions for long periods in both sea and air in order to improve our understanding of the large-scale and scale interactions. She presented observations of surface winds from the recently launched Quikscat satellite and showed how these data can improve analyses of winds within hurricanes and can even detect surface circulations prior to tropical cyclogenesis. She described a project to combine information from Quikscat, ERS-2, and SSM/I to generate decade-long global estimates of surface fluxes and showed preliminary analyses from this study.

Dr. Elizabeth Ritchie from the Naval Postgraduate School in Monterey presented a talk on "*Some aspects of midlevel vortex dynamics in tropical cyclone genesis*" and focused on the question of what processes occur to generate a tropical cyclone from large-scale conditions. While the thermodynamic conditions for cyclogenesis are often met over the tropical oceans, tropical cyclone formation is still rare. She stressed the importance of pre-existing disturbed weather and the need for a mechanism to reduce the Rossby radius of deformation from that of the large-scale environment (~2000 km) to that of a hurricane (~500 km). She suggested that mesoscale convective systems (MCSs) represent such a mechanism because of their tendency to produce midlevel cyclonic vortices. Examination of 80 tropical cyclones in the western Pacific revealed 78 of the cases were associated with at least one MCS in the 72-h prior to

cyclogenesis. About 70% of the cases had MCSs at multiple times during that period and 44% had multiple MCSs at a single time. Dr. Ritchie suggested that a merger of coexisting vortices can lead to a larger and stronger vortex with vorticity filaments extending outward. A merger also leads to a deeper vortex, and in environments with sufficient background vorticity, can result in the extension of the vortex to the surface. She showed an example of vortex merger and subsequent tropical cyclogenesis using data from Tropical Cyclone Oliver (1993) during the TOGA-COARE experiment. Oliver developed from two MCSs in close proximity to each other in a monsoon trough. The vortices rotated around each other and gradually moved closer together. One of the vortices associated with the MCSs became the dominant circulation while the other formed an outer rainband.

2.5 Clouds and cloud systems

This session was divided into two subsessions, observation and modeling, and was chaired by Drs. M. Garstang (University of Virginia), W. Cotton (Colorado State University), W.-K. Tao (Goddard Space Flight Center), and J. Halverson (U. of Maryland at Baltimore and Goddard Space Flight Center).

Professor Michael Garstang of the U. of Virginia presented a talk entitled "*Cumulus Cloud Roots: Their origins, roles and consequences*". He showed that cumulus clouds that develop in the tropics (ocean and land) are mainly initiated by perturbations on the upper surface of the mixed layer. These perturbations have little or nothing to do with discontinuities at the surface. He also thinks that the perturbations are forced by subtle changes in mixed layer circulations (three-dimension velocity fields). He applied isotopic analysis and suggested that the convective part of storm systems draw upon very large (~ 1000 km) regions of mixed layer inflow. The stratiform portion draws initially upon fractionated water sources but ultimately upon less processed air. He also discussed Dr. J. Simpson's view on "cumulus roots and hot towers". His observational results (perhaps, the first direct measurements) indicated that "cloud cores" can transport 2000-2500 W/m² but only occupy 1% of the cloud area. This result was consistent with the "hot towers" hypothesis.

Dr. Edward Zipser of the University of Utah presented a talk entitled "*Field programs in tropical meteorology after Joanne's first 50 years: Are there any important objectives remaining?*". Dr. Zipser pointed out that field programs are there to help understand the theories (i.e. hot towers, fire boxes) better and to develop new theories. By using a lot of observational data, we can now better understand mesoscale convective systems and their associated two types of downdrafts, convective scale and mesoscale. Dr. Zipser also discussed the relationship between large-scale environments and their embedded convective systems. He showed that large-scale ascent is needed for deep convective activity in the tropics. Different draft characteristics are observed for tropical oceanic convection. Oceanic convection is always associated with weaker and narrower core updrafts compared to continental convection. He also presented a modified "hot towers" hypothesis. The oceanic narrow core drafts can be diluted, but ice processes above the freezing level can provide the latent heat release (5-10 K) necessary to have high potential temperatures at cloud top (15 km level).

Professor Robert Houze of the University of Washington presented a talk entitled "*Hot towers to superclusters: Advances in tropical convection over the last 40 years*". Professor Houze presented the major findings related to tropical convection since 1960. In the 1960's, the "hot tower" hypothesis was proposed, and the first satellites were launched to aid research in tropical meteorology. By the 1970's, the stratiform component of tropical convective systems was well recognized. Stratiform precipitation is a manifestation of the upscale organization of the hot towers. Major developments in the area of parameterizations of tropical convection were also proposed in the 1970's. The effects of tropical convection on heating and momentum were examined using models and observations in the 1980's. As the scale of the up- and downdrafts increases, the vertical distribution of heating and momentum flux convergence changes. During the last decade of the 20th century, superclusters were documented and their relationship to tropical convection and large-scale waves was recognized. Superclusters have mesoscale downdrafts that may play an especially important role in the momentum transport in large-scale tropical waves. In addition, the natural variability of deep tropical convection as measured by rain area size, stratiform proportion, and satellite-detected cloud top structure appears to be

chaotic. With the launch of TRMM in 1997, the bounds of the natural variability of tropical convection can be determined.

Dr. Margaret LeMone of the National Center for Atmospheric Research presented a talk entitled "*What we have learned about doing field programs*", illustrated by several experiences depicted in cartoons drawn by her and others over the last 25 years. She discussed how a field campaign was planned and carried out. A hypothesis, followed by a detailed scientific and operations plan developed by a group of scientists, was needed before any field campaign. The use of quantitative models to evaluate field-program results even during the field program is relatively new; Dr. J. Simpson was a pioneer in the use of models for cloud seeding experiments. However, Dr. LeMone cited examples in which too literal interpretation of model results or data on a screen have led to trouble (missing an important observation, an overidealized view of phenomena). As an example of the latter, she noted the shift in idealization of the daytime fair weather planetary boundary layer wind profile from the Ekman Spiral to the mixed layer, with wind shear only at the top and bottom. This conceptual model was reinforced by aircraft observations taken mainly in nearly steady-state conditions (to gain a sufficient statistical sample) and large eddy simulations (LES) run to simulate statistically steady-state conditions. She showed that such a PBL over land exists from around noon to midafternoon, local time; and used data from two similar fair-weather days to illustrate how continued boundary-layer growth could lead to PBL wind shear even during this time of day. Such situations indicate the importance of observations and LES studies of evolving situations. She emphasized that subsequent data analysis and modeling are the most important part of field programs, using statistics from GATE and CCOPE to show that it takes five to six years to reach a peak in the number of publications (GATE is experiencing a secondary peak 25 years after the experiment). She praised NASA for its continued support of FIFE, an experiment whose long publication record was illustrated by a special issue of JAS over 10 years after the experiment. Such sustained funding facilitates the important collaborations and data-sharing necessary for the synergistic blending of diverse data and ideas that make the most successful field programs. Dr. LeMone also talked about women in meteorology, comparing the results of the survey she and Simpson did in the early 1970s to more recent data, which reflect an increase in the number of women in the atmospheric sciences, and a reduction and shift of the problems

they encounter in their careers. She closed by citing the potential additional benefit of women in science because women can bring a different set of experiences and hence a different outlook.

Dr. Bill Cotton of Colorado State University (CSU) presented a review of progress made in numerical cloud modeling since the very early days through the present. Dr. Cotton commented that Dr. Simpson played an instrumental role nearly every step of the way throughout the evolution of these models. The very first 1D models engendered debate as to whether cumulus clouds should be properly represented as either bubbles or plumes. These were followed by the 1.5D, time dependent models with dynamic entrainment through rigid cylindrical walls, and then the axisymmetric and slab-symmetric models of Ogura, Murray, Soong, Orville and Lau. One of the first 3D models was run on a Univac 1108, which occupied a whole room and required an entire weekend to compute 10 minutes worth of cloud evolution. This is in stark contrast with the 3D cloud models of today, capable of simulating an F4 tornadic vortex complete with secondary vortices, starting with initial synoptic observations and inclusion of land use variations. The 3D cloud ensemble models, pioneered by Drs. Tao and Simpson, have now been coupled with a dynamic ocean model. This coupled model can simulate stable fresh-water lenses in the upper ocean layer generated by rainwater influx, which compete for control of water column stratification against outflow gust-induced mixing of the ocean layer. Dr. Cotton discussed the continuing evolution of the CSU-RAMS model, which is being expanded to a nested global domain, and new findings on stratiform cloud deck properties as simulated with bin-resolving microphysical models. Finally, he concluded with examples of real-time NWP using the CSU-RAMS, which is capable of forecasting convective events along the Colorado Front Range out to 48 hours at a grid resolution of 3 km. This requires only 5-hours of processing on a \$21,000 PC cluster.

In his talk, Dr. Brad Ferrier presented a synopsis of his many years of research into factors controlling the precipitation efficiency of mesoscale convective systems. Where precipitation efficiency is defined as the ratio of surface rainfall to total condensation, Dr. Ferrier used the Goddard Cumulus Ensemble (GCE) model to investigate factors that constrain this ratio, including updraft tilt and cloud microphysical processes. His simulations have included

the case of both a mid-latitude continental squall system (COHMEX storm) and a GATE system representative of the oceanic tropics. For the same initial thermodynamic sounding in each case, the vertical shear was allowed to vary between runs. This profoundly affected updraft tilt, with simulations ranging from upshear tilted, to erect, through downshear orientation. From these simulations, Dr. Ferrier surmised that erect updrafts are most efficient...by virtue of very effective collection of cloud water by precipitation. At the opposite extreme, the upshear-tilted systems -- with their broader region of stratiform rain -- lose substantial rainwater mass due to evaporation in subsaturated layers. Dr. Ferrier's talk concluded with a moving tribute to Dr. Joanne Simpson, in praise of her leadership, visionary scientific contributions and dogged determination throughout the years - a "planet which many satellites orbit around."

Dr. Wei-Kuo Tao presented a synopsis on the current and future application of the GCE for understanding precipitation processes. Dr. Tao began by presenting a long list of university and laboratory groups with whom the GCE modeling team has collaborated with over the years. Foremost among Dr. Tao's associations is his continuing close work with Dr. Simpson. Dr. Tao began by presenting their early work involving cumulus mergers over Florida. Whereas the largest and most persistent convective clouds are often formed from merging of adjacent cells, the merger process yields an order of magnitude more rain than in unmerged cells. The GCE model studies suggest that the primary merger mechanism involves cloud downdrafts and cold pools. Since the time of the first simulations made with the GCE in 1982, Dr. Tao's group has published more than 70 papers with contributions from 50 young scientists. In its current generation, the 3D GCE incorporates numerous physical processes including a four-class ice scheme, parameterized land-atmosphere-cloud exchange (PLACE) and several oceanic PBL schemes. The GCE has been used to simulate diverse meteorological phenomena ranging from cirrus clouds to three-dimensional convective systems; cloud chemistry and tracers; a new hypothesis on cloud-radiation interactions; and idealized climate simulations. In the future, the GCE will be coupled to a regional scale model (MM5) and also the Goddard Data Assimilation Office (DAO) model to study seasonal climate on regional-global scales. The GCE will also continue to serve as the key linkage relating TRMM-observed precipitation structures to profiles of latent heating in the tropics.

3. Summary of Concluding Remarks: Dr. Joanne Simpson

The final speaker, Dr. Joanne Simpson, opened by exclaiming "This symposium has been the most exciting and rewarding experience in my half century as a meteorologist". Joanne stressed that the main lesson about science is that to move forward in research, it is necessary to make many mistakes and then to use the learning from these to find the way to formulate better hypotheses. A case in point is the long number of years she and Herb Riehl kept asking "*Why are there so few hurricanes?*" The two sought to find both necessary and sufficient conditions for tropical cyclone formation. According to Joanne, we now know that seeking "sufficient conditions" is not useful and that cyclone formation is a probabalistic not a deterministic process. Critical requirements are dynamic interactions between several scales of motion. These interactions must be effective in the lower boundary layer which has a very high energy content, and there must be high background vorticity. The Rossby radius must be decreased by nearly an order of magnitude from its normal tropical value of about 2000 km. When the Rossby radius is not lowered, all the latent heat released by convective cloud systems is radiated away by gravity waves. The strong lateral shear across a monsoon trough can occasionally lower the Rossby radius enough to allow several convective vortices about 300 km across to survive and merge with each other.

Dr. Simpson continued by describing her experiences in working on the TRMM project as "one of the greatest learning processes and most fun experiences in my life". The most innovative part of TRMM was and is to use rain radar and passive microwave together so that the joint measurement is better than either one alone. The algorithms that take the radiances from the instruments to derive tropical rainfall and associated latent heating have worked amazingly well. The products have been realistic and useful. And there have been some unplanned benefits such as new views by the TRMM radar of tropical cyclones around the globe.

Dr. Simpson concluded by saying she has been extremely lucky to have been a meteorologist in this half century "when the field has gone from the horse and buggy to the space age". In an emotional ending to the seminar's three days, Dr. Simpson warmly thanked all of the people who arranged the